Electrical Power and Energy Systems 105 (2019) 131–141

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

journal homepage: www.elsevier.com/locate/ijepes

A synchrophasor measurement based wide-area power system stabilizer design for inter-area oscillation damping considering variable time-delays

Tapan Prakash[a,*], Vinay Pratap Singh[a], Soumya R. Mohanty[b]

[a] Department of Electrical Engineering, National Institute of Technology Raipur, Raipur 492010, India
[b] Department of Electrical Engineering, Indian Institute of Technology (BHU), Varanasi 221005, India

ARTICLE INFO

Keywords:
Jaya algorithm
Inter-area oscillations
Phasor measurement units
Time-delay compensator
Wide-area power system stabilizer

ABSTRACT

Owing to the everlasting growth of power demand and continual change in configuration of modern power system, the role of electric utility in supplying secure and reliable power has become more prominent. Presently, the ongoing interconnections of existing power system are adding more complexity to the system and consequently, making it exposed to small-signal stability issues related to inter-area oscillations. If these issues are not adhered efficiently then it may lead to system voltage collapse and even blackouts. However, incorporation of a properly designed power system stabilizer (PSS) based on information received from wide-area measurements can solve the problem. Moreover, design of such PSS is still a challenging task as the network uncertainties are highly unpredictable. The remote signals obtained through wide-area measurement system (WAMS) are needed to be transferred to control center via communication channel. However, this process makes the system subjected to inherent communication time-delays. Consequently, the performance of PSS using these signals may deteriorate if these delays are not compensated appropriately. This motivated the present work of the design of wide-area power system stabilizer (WAPSS) utilizing information contained in synchrophasor measurements for inter-area oscillation damping considering variable communication time-delays. To obtain wide-area synchrophasor measurements, phasor measurement units (PMUs) compliant to IEEE C37.118.1 principles are adopted. The variability in communication time-delays are compensated by a time-delay compensator (TDC) designed using *Simevents* toolbox available with MATLAB. Based on geometric measures of controllability and observability, the choice of location of WAPSSs and the selection of their respective input signal are obtained. The parameters of WAPSSs are tuned by recently proposed, simple yet efficient, Jaya algorithm (JA). Different case studies of small-signal analysis and nonlinear time-domain simulations are carried out on New England 39-bus test system operating under diverse conditions. The obtained results establish the achievement of desired performance by the JA based WAPSSs regarding inter-area oscillation damping under consideration of variable communication time-delays.

1. Introduction

As a consequence of tremendously increasing power demand, the existing power generation facilities are adopting capacity expansions or interconnections as a tool to tackle the situation of inadequacies in meeting demand. The interconnections of existing power networks are preferred more over capacity expansions due to practical limitations of such expansions. These interconnections resulted in newly developed networks [1–4]. However, the responsibility of supplying secure and reliable power in an interconnected system has greatly increased for an electric utility.

In an interconnected system, small-signal stability issues related to inter-area oscillations are observed to be more prominent and are needed to be tackled efficiently. If these issues are not addressed properly, then they may lead to total system voltage collapse and even blackouts [5,6]. As a result, it is required to monitor the whole system on a real-time platform so as to have enhanced knowledge of any occurrence of these oscillations in the system. Such kind of monitoring is presently possible with the aid of wide-area measurement system (WAMS) [7]. Phasor measurement units (PMUs), which are an integral part of WAMS, are capable of measuring time-synchronized voltage and current phasors. These measured phasors carry vital information about dynamics of the system [8]. Thus, the measurements provided by WAMS are very much helpful in taking corrective measures in case of any system failure or voltage collapse scenario.

Traditionally, the power system stabilizers (PSSs) installed at

* Corresponding author.
E-mail address: tapanprakashsinha@gmail.com (T. Prakash).

https://doi.org/10.1016/j.ijepes.2018.08.014
Received 25 April 2018; Received in revised form 19 July 2018; Accepted 17 August 2018
0142-0615/

Nomenclature

α_j^k	random number during kth iteration
β_j^k	random number during kth iteration
$\Delta\omega_{i-j}$	rotor speed difference between ith and jth generators
$\Delta\theta_{i-j}$	rotor angle difference between ith and jth generators
f_0	nominal frequency
A	state matrix
A_w	state matrix of WAPSS
B	input matrix
B_w	input matrix of WAPSS
C	output matrix
C_w	output matrix of WAPSS
D	number of decision variables
D_w	feedforward matrix of WAPSS
e_y	measurement error of y
Gi	ith generator (i = 1–10)
K_c	controller gain
K_W	washout coefficient
N	number of candidate solutions
T_i	coefficients of lead-lag compensator (i = 1, 2, 3, and 4)
t_r	event-trigerring sequence
t_s	total simulation time
u	control input
x	system state
x_{best}^k	best solution at kth iteration
x_{worst}^k	worst solution at kth iteration
x_w	WAPSS states
$X_{i,j}^k$	jth decision variable of the ith updated solution
$x_{i,j}^k$	jth decision variable of the ith candidate solution
y_i	system output (i = number of outputs)
Z_i^k	selected candidate solution taking part in (k + 1)th iteration

excitation system of each generators are utilized for power oscillation damping. The rotor speed of generators and/or active power flow in lines in each area serve as inputs to PSSs of respective area. These signals lack information of the whole power system. Due to their limited observability, local PSSs are not much capable of damping inter-area oscillations which are often observed in interconnected systems. However, wide-area signals available from WAMS can effectively be exploited to design wide-area PSS (WAPSS) to damp out inter-area oscillations [9]. But, these signals are inherently subjected to communication time-delays which can adversely affect the performance of WAPSSs [10]. The time-delay depends upon various factors like type of communication link used, network distance, transmission protocols, system loads, etc. and it can range from tens to several hundreds of milliseconds [11]. Various efforts to deal with these delays are reported in literature. Most commonly used method to cater time-delays is Padé approximation [12] in which a fixed time-delay of first or second order is generally considered. However, in practice the communication time-delay is variable in nature and WAPSS designed by considering fixed time-delays cannot perform satisfactorily when exposed to variable delays. The Lyapunov stability theory and linear matrix inequalities (LMI) approach are adopted in [13] for the design of wide-area damping controller with network delays. A generation rescheduling approach is utilized in [14] to design WAPSS. The predictive control schemes are adopted to cater variable time-delays in [15,16]. A predictor based method is proposed in [17] for delay compensation. However, this technique works well only if accurate system model is available. Several other methods [18–20] are reported in literature considering lead-lag compensator with fixed parameters to damp inter-area oscillations which can tolerate variable time-delays within a small range.

The variable time-delays can extend to a larger range due to routing problems and congestion in the network [21,22]. To ensure effective performance by a WAPSS, these remarkable delay variations should be compensated adaptively. Much of the works reported in available literature have concentrated their focus on either fixed time delays or variable time-delays of small range. However, there are still efforts required to compensate large variable time-delays occurring due to network uncertainties and communication constraints. In [23], a game-theoretic multi-agent control and allocation of network cost under communication constraints is presented. An adaptive delay compensator for wide-area damping controller (WADC) is proposed in [24] to compensate variable time delays. In [25], network input and output delays with packet drop is considered in the design of WADC whereas variable time-delays are compensated using appropriate phase lead and the methodology described in [26]. A cyber-physical architecture which is delay-aware is designed for wide-area control of power systems in [27]. In [28], dynamic clustering and TCSC redesigns are utilized for wide-area control of large power systems. A dynamic control allocation strategy is adapted to damp out inter-area oscillations in [29]. Design of damping controller on the basis of structured dynamic model equivalent model is presented in [30].

While most of the reports in literature assume the presence of PMUs in design of WAPSS, but in this work, PMUs compliant with C.37.118.1 principles are installed in the studied network to obtain synchronized

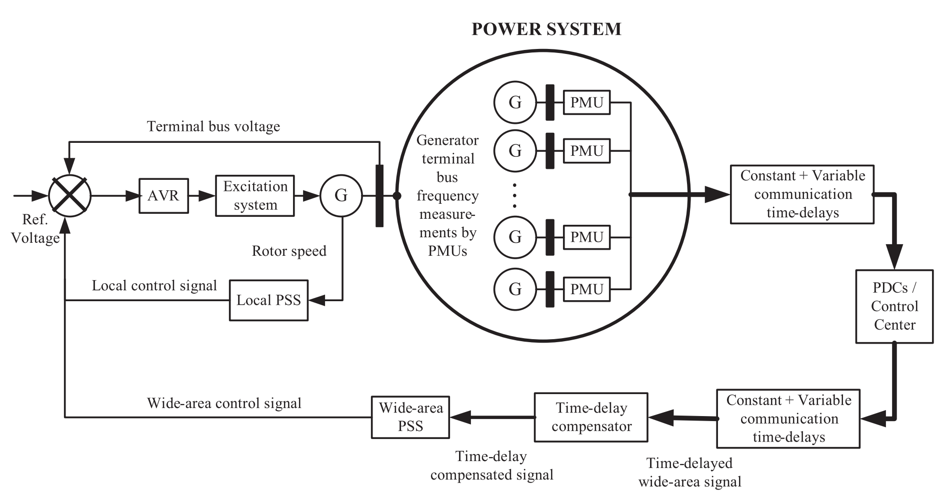

Fig. 1. Proposed network control scheme.